Quarkonium spectral functions at *T>0*

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Three common myths about quarkonium spectral functions at *T>0*:

1) Lattice QCD tells that quarkonium states survive up to $2T_c$

2) It is unclear whether the internal energy or the free energy or their combination should be used in the potential models

3) Quarkonium yield measures Debye screening in the hot medium and thus its temperature

STAR Collaboration Meeting, Berkley, Nov. 16, 2011

Myth #1 :
Lattice QCD tells that quarkonium states survive up to $2T_c$

What is T_c anyway ?

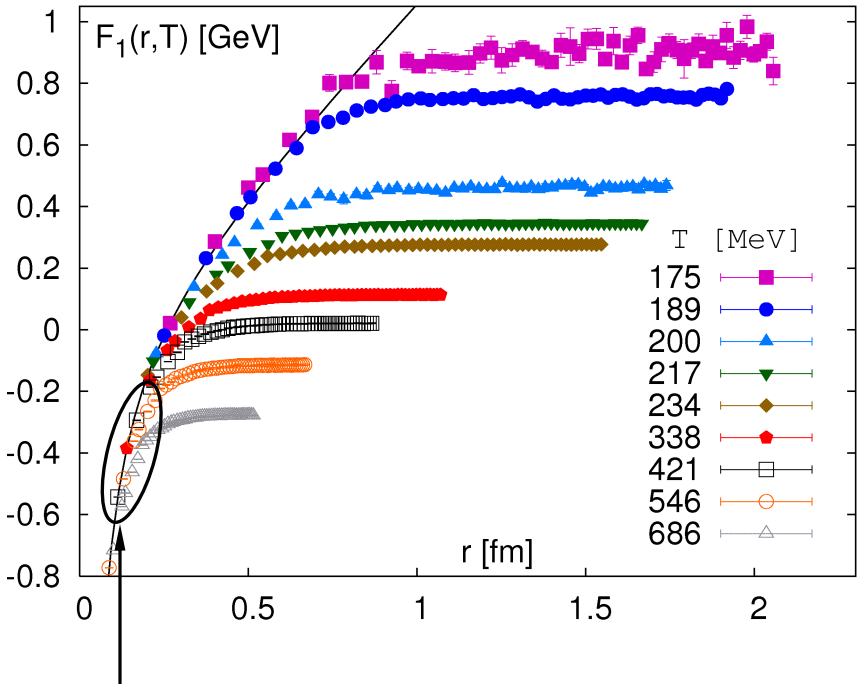
What do we know ?

What do (can) we calculate ?

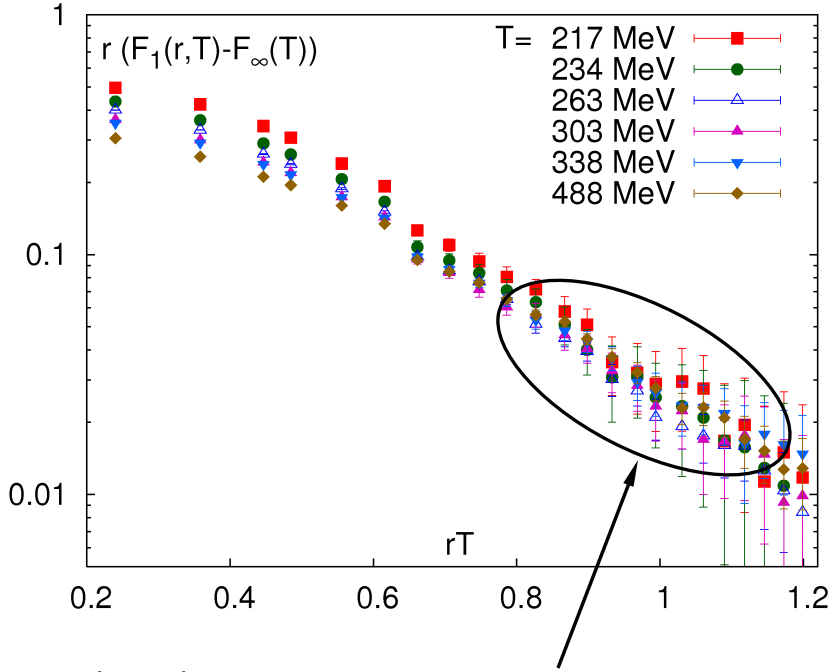
What do we know? Color screening in lattice QCD

p4 action, $(2+1)-$flavor QCD, $16^3 \times 4$ lattices, $m_\pi \simeq 220$ MeV

P.P., JPG 37 (10) 094009 ; arXiv:1009.5935



$F_1(r,T)$ T-independent at short distances



$F_1(r,T)$ scales with T and is exponentially screened for $r > 0.8/T$

Significant temperature dependence of the static quark anti-quark free energy for $r \simeq 0.3 - 0.5$ fm.

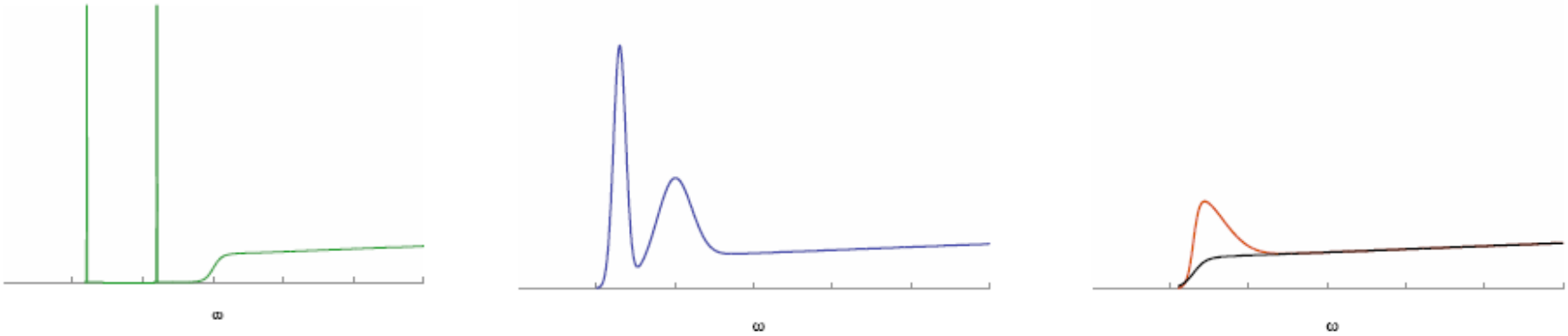
charmonium melting @ RHIC Digal, P.P., Satz, PRD 64 (01) 094015

Quarkonium spectral functions

In-medium properties and/or dissolution of quarkonium states are encoded in the spectral functions

$$\sigma(\omega,p,T) = \frac{1}{2\pi}\,\mathrm{Im}\int_{-\infty}^{\infty} dt e^{i\omega t}\int d^3x e^{ipx}\langle[J(x,t),J(x,0)]\rangle_T$$

Melting is see as progressive broadening and disappearance of the bound state peaks



Due to analytic continuation spectral functions are related to Euclidean time quarkonium correlators that can be calculated on the lattice

$$G(\tau,p,T) = \int d^3x e^{ipx}\langle J(x,-i\tau),J(x,0)\rangle_T$$

MEM

$$G(\tau,p,T) = \int_0^{\infty} d\omega\sigma(\omega,p,T)\frac{\cosh(\omega\cdot(\tau-\frac{1}{2T}))}{\sinh(\omega/(2T))}$$

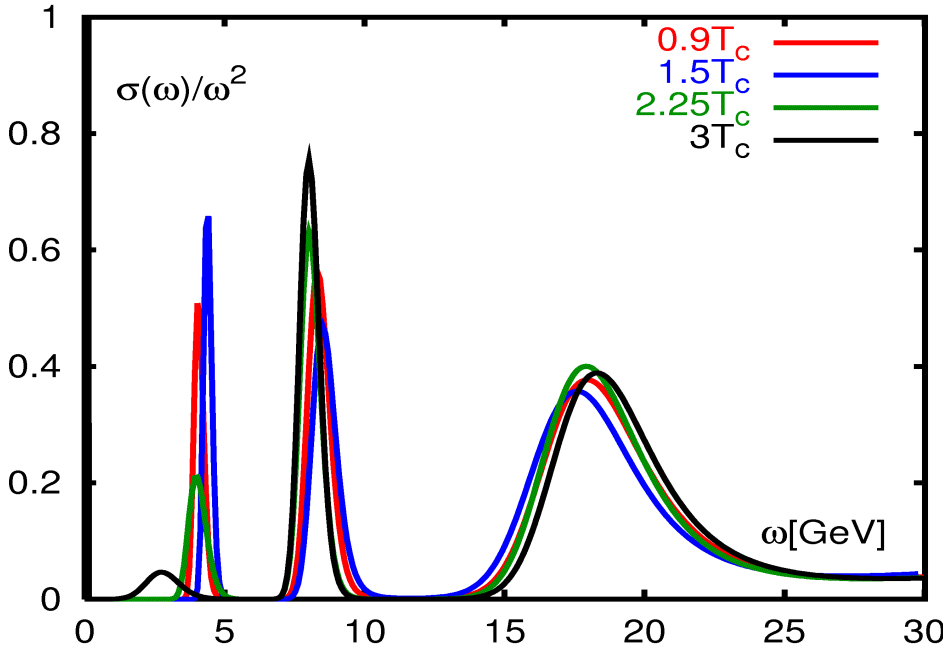
$\Rightarrow$ $\sigma(\omega,p,T)$

1S charmonium survives to $1.6T_c$??

Umeda et al, EPJ C39S1 (05) 9, Asakawa, Hatsuda, PRL 92 (2004) 01200, Datta, et al, PRD 69 (04) 094507, ...

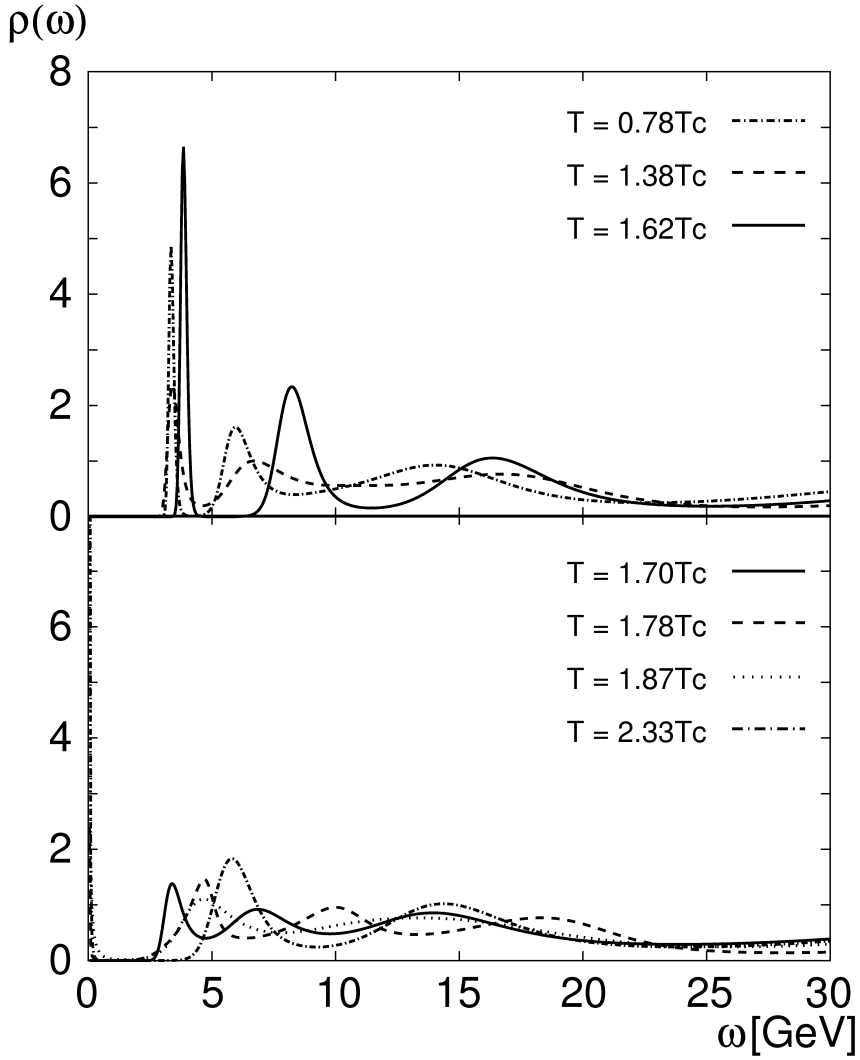
Charmonium spectral functions from MEM (the early days)

Isotropic lattice, N_τ=12-40, a^{-1}=9.72GeV
Datta, Karsch, P.P, Wetzorke,
PRD 69 (2004) 094507,



If bound state peaks exist then what about color screening ?

Anisotropic lattice, N_τ=32-80, a^{-1}=20GeV
Asakawa, Hatsuda, PRL 92 (04) 012001



What do we calculate on the lattice? Charmonium correlators at T>0

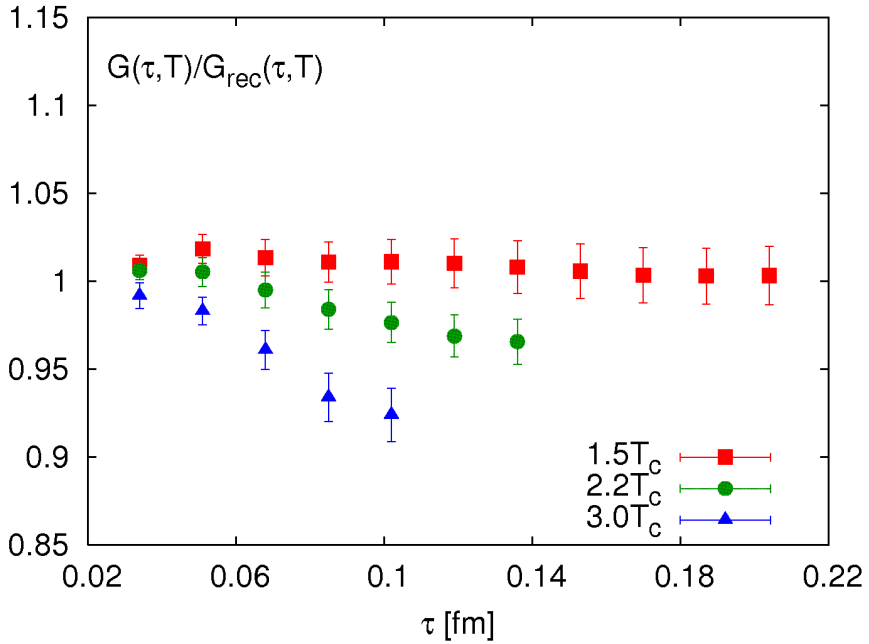
temperature dependene of $G(\tau,T)$

$$G(\tau,T)=\int_0^\infty d\omega\sigma(\omega,T)\frac{\cosh(\omega(\tau-1/(2T)))}{\sinh(\omega/(2T))}$$

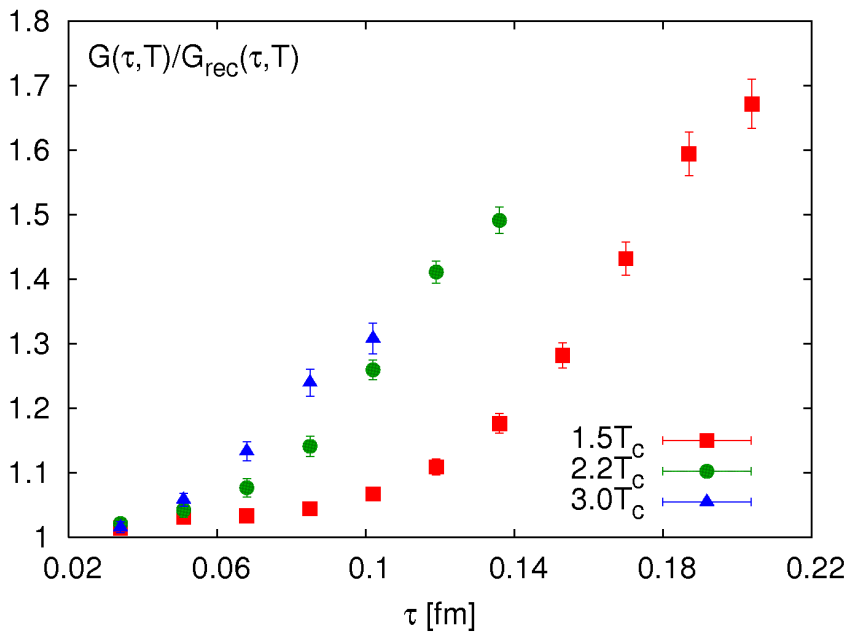
If there is no *T*-dependence in the spectral function, $G(\tau,T)/G_{rec}(\tau,T)=1$

$$G_{rec}(\tau,T)=\int_0^\infty d\omega\sigma(\omega,T=0)\frac{\cosh(\omega\cdot(\tau-\frac{1}{2T}))}{\sinh(\omega/(2T))}$$

Pseudo-scalar $\Leftrightarrow 1S$



Scalar $\Leftrightarrow 1P$

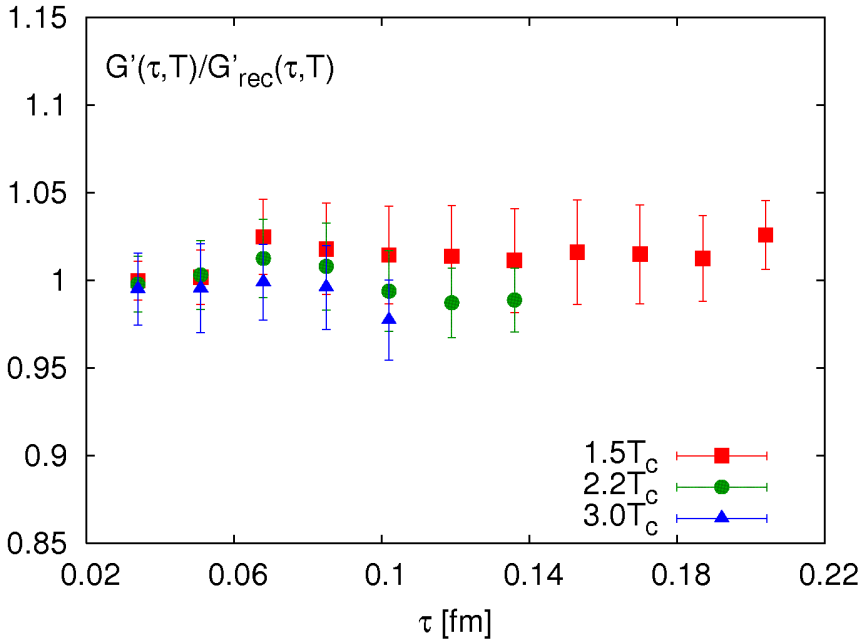


Datta, Karsch, P.P., Wetzorke, PRD 69 (04) 094507

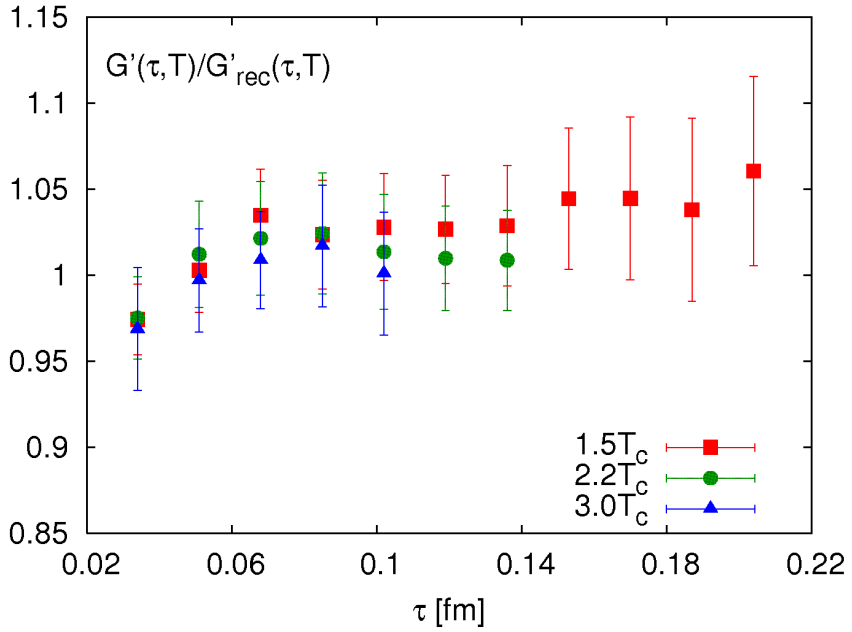
Charmonium correlators at *T>0*

zero mode contribution is not present in the time derivative of the correlator
Umeda, PRD 75 (2007) 094502

Pseudo-scalar $\Leftrightarrow 1S$



Scalar $\Leftrightarrow 1P$



P.P., EPJC 62 (09) 85

the derivative of the scalar correlators does not change up to $3T_c$, all the T-dependence was due to zero mode

either the 1P state (χ_c) with binding energy of *300*MeV can survive in the medium with ε=*100*GeV/fm^3

or temporal quarkonium correlators are not very sensitive to the changes in the spectral functions due to the limited $\tau_{max}=1/(2\,T)$

Charmonium spectral functions on the lattice at T=0

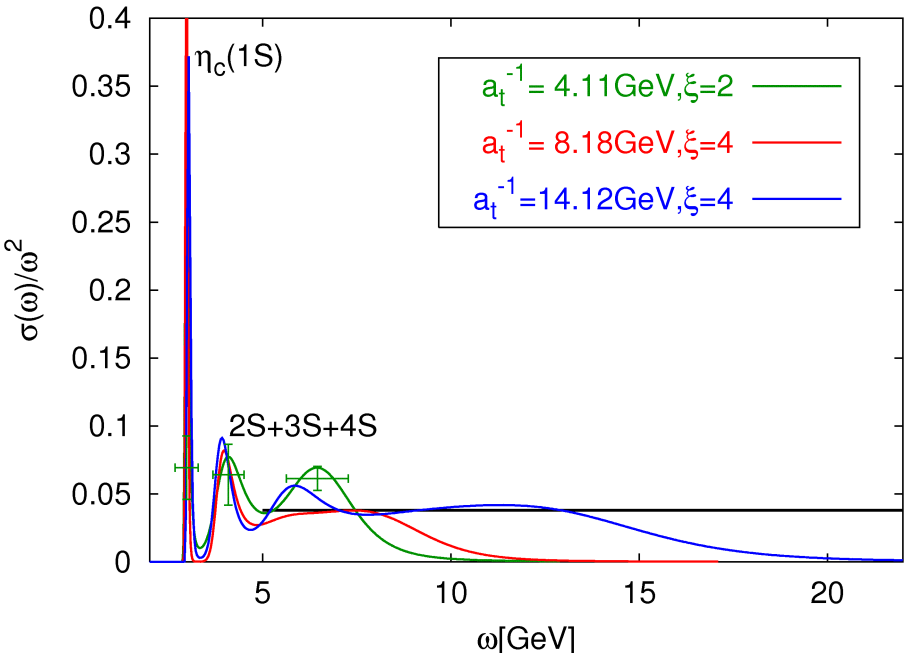
Anisotropic lattices: $16^3 \times 64, \xi = 2$ $16^3 \times 96, \xi = 4$, $24^3 \times 160, \xi = 4$

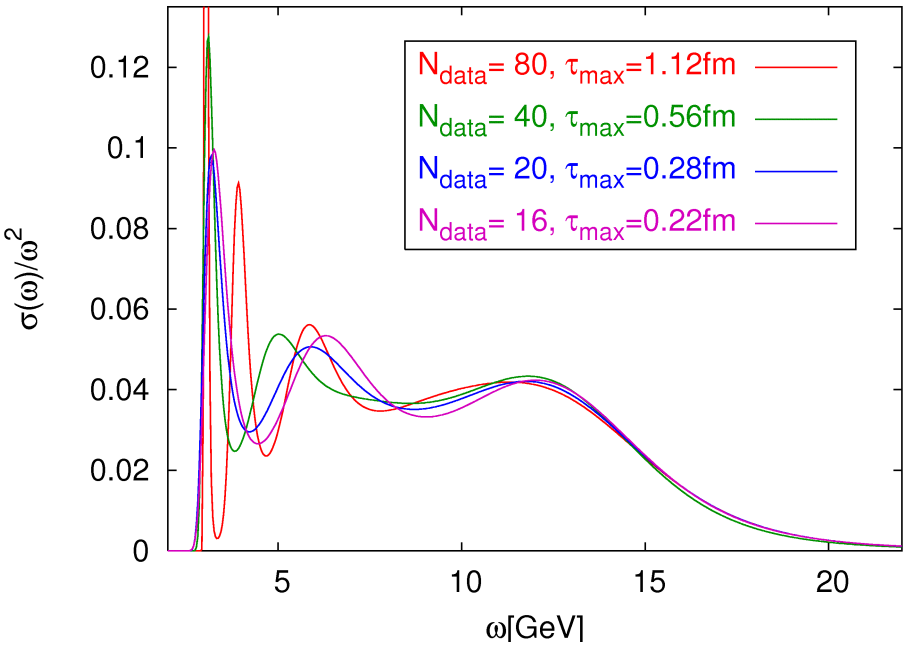
$L_s = 1.35 - 1.54$fm, #configs=500-930;

Wilson gauge action and Fermilab heavy quark action

Jakovác, P.P., Petrov, Velytsky, PRD 75 (07) 014506

Pseudo-scalar (PS) $\rightarrow$ S-states



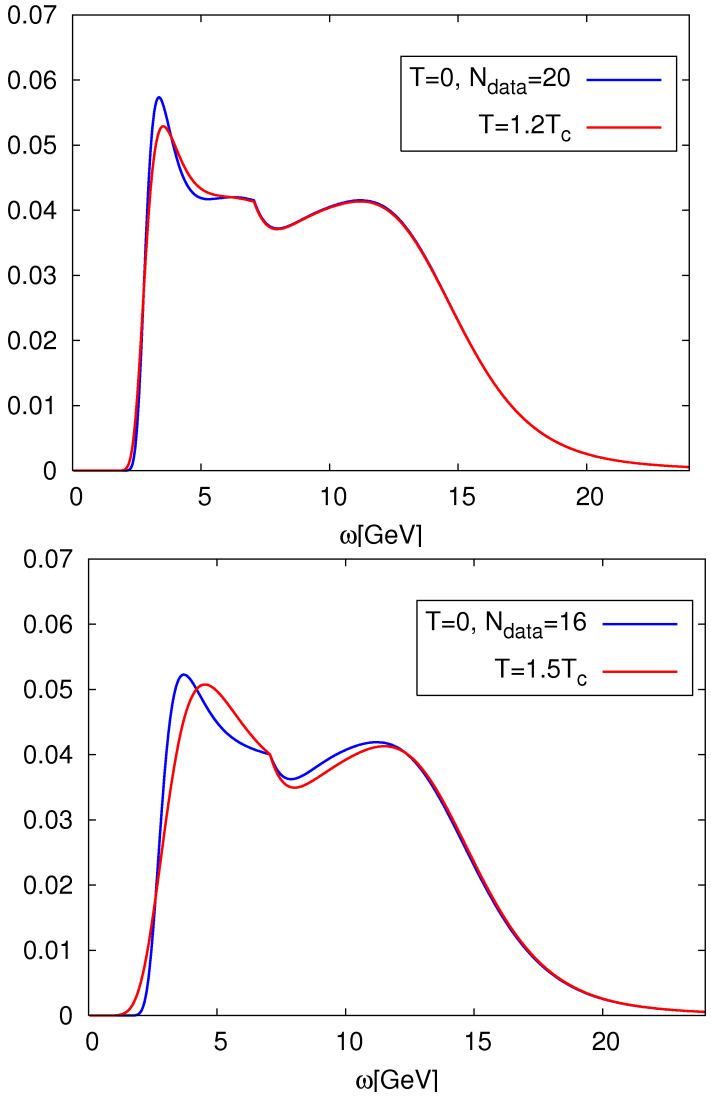


For $\omega > 5$ GeV the spectral function is sensitive to lattice cut-off ;

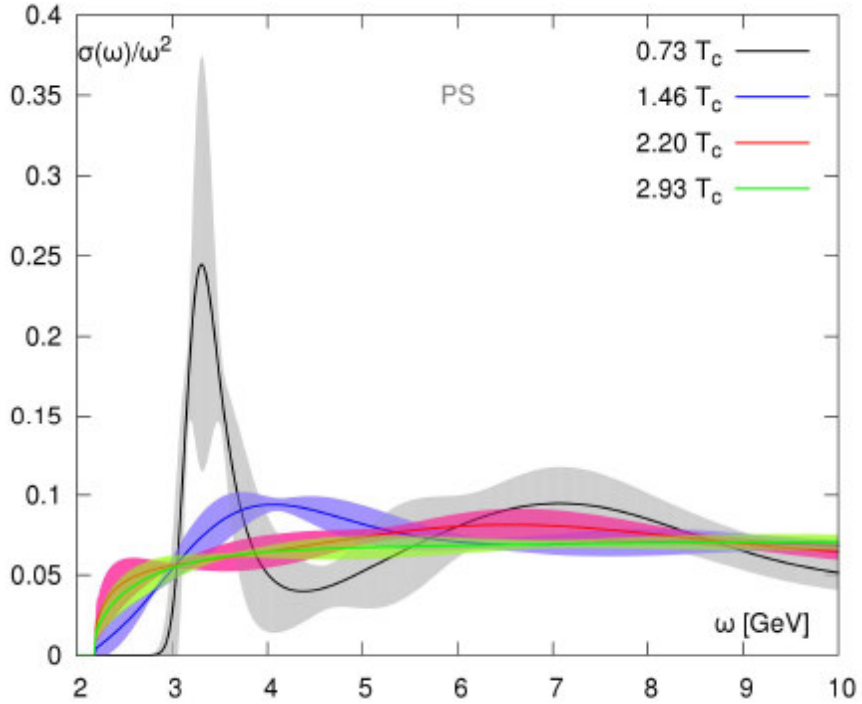
ground state peak is shifted, excited states are not resolved when τ_{max}, N_{data} become small

Charmonium spectral functions on the lattice at T=0

Anisotropic lattice calculations
Jakovác, P.P., Petrov, Velytsky, PRD 75 (07) 014506



state of the art isotropic lattice : H.-T. Ding, A. Francis, O. Kaczmarek, F. Karsch, H. Satz, W. Soeldner, PoS Lattice2010 180
N_τ=24-96, a^{-1}=18.97GeV



No clear evidence for charmonium bound state peaks from MEM spectral functions !

Lattice QCD based potential model

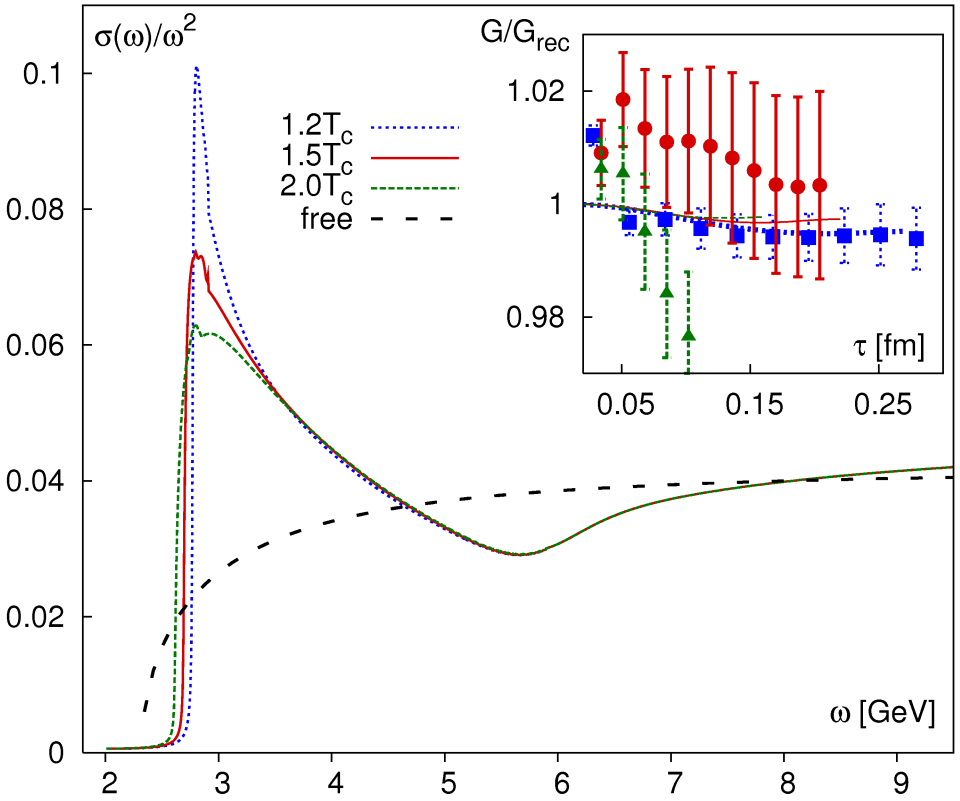
If the octet-singlet interactions due to ultra-soft gluons are neglected :

$$\left[i\partial_0 - \frac{-\nabla^2}{m} - V_s(r,T)\right] S(r,t) = 0 \quad \Rightarrow \quad \sigma(\omega,T)$$

potential model is not a model but the tree level approximation of corresponding EFT that can be systematically improved

Test the approach vs. LQCD : quenched approximation, $F_1(r,T) < \mathrm{Re}V_s(r,T) < U_1(r,T)$, $\mathrm{Im}V(r,T) \approx 0$

Mócsy, P.P., PRL 99 (07) 211602, PRD77 (08) 014501, EPJC ST 155 (08) 101



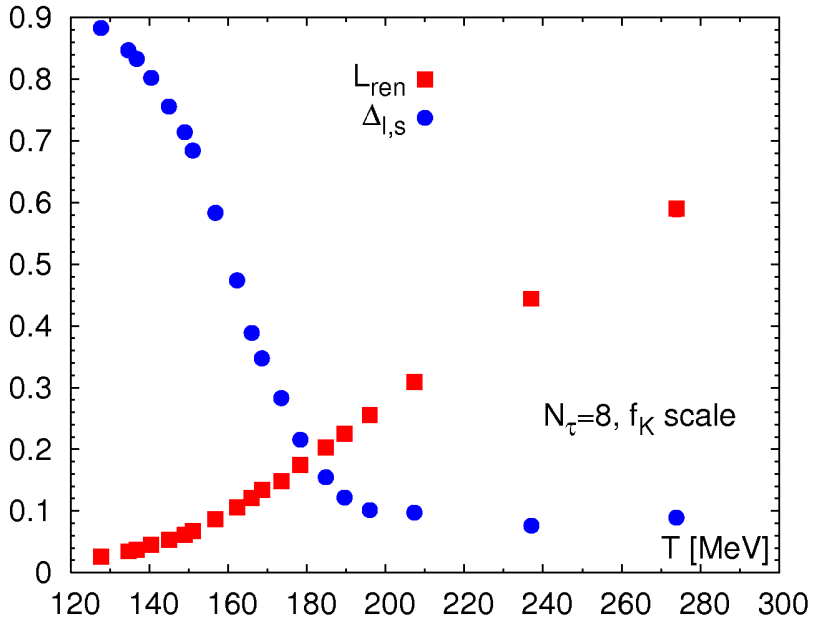
- resonance-like structures disappear already by $1.2T_c$
- strong threshold enhancement above free case

  => indication of correlations
- height of bump in lattice and model are similar
- The correlators do not change significantly despite the melting of the bound states => it is difficult to distinguish bound state from threshold enhancement in lattice QCD

What is T_c ?

In QCD with no light dynamical quarks (pure gauge theory) there is 1st order deconfining transition => the Polyakov loop L=exp(-F_Q/T) is the order parameter

In QCD with physical quark masses there is only an analytic crossover
Aoki et al, Nature 443 (2006) 675
=> L is not an order parameter => defining T_c from L is wrong !



Gupta et al, Science 332 (2011) 1525
T_c = *175(+1)(-7)* MeV

Chiral crossover temperature can be defined : T_{chiral} = *154(9)* MeV (HotQCD)
T_{chiral} =*(147-157)* MeV (BW)

better to avoid quoting T_c, use T in MeV instead

Spatial charmonium correlators

Spatial correlation functions can be calculated for arbitrarily large separations $z \to \infty$

$$G(z,T) = \int_0^{1/T} d\tau \int dxdy \langle J(\mathbf{x}, -i\tau), J(\mathbf{x}, 0)\rangle_T, \quad G(z \to \infty, T) \simeq Ae^{-m_{scr}(T)z}$$

but related to the same spectral functions $G(z,T) = \int_{-\infty}^{\infty} e^{ipz} \int_0^{\infty} d\omega \frac{\sigma(\omega,p,T)}{\omega}$

Low T limit :

$\sigma(\omega,p,T) \simeq A_{mes}\delta(\omega^2 - p^2 - M_{mes}^2)$

$A_{mes} \sim |\psi(0)|^2 \to m_{scr}(T) = M_{mes}$

$G(z,T) \simeq |\psi(0)|^2 e^{-M_{mes}(T)z}$

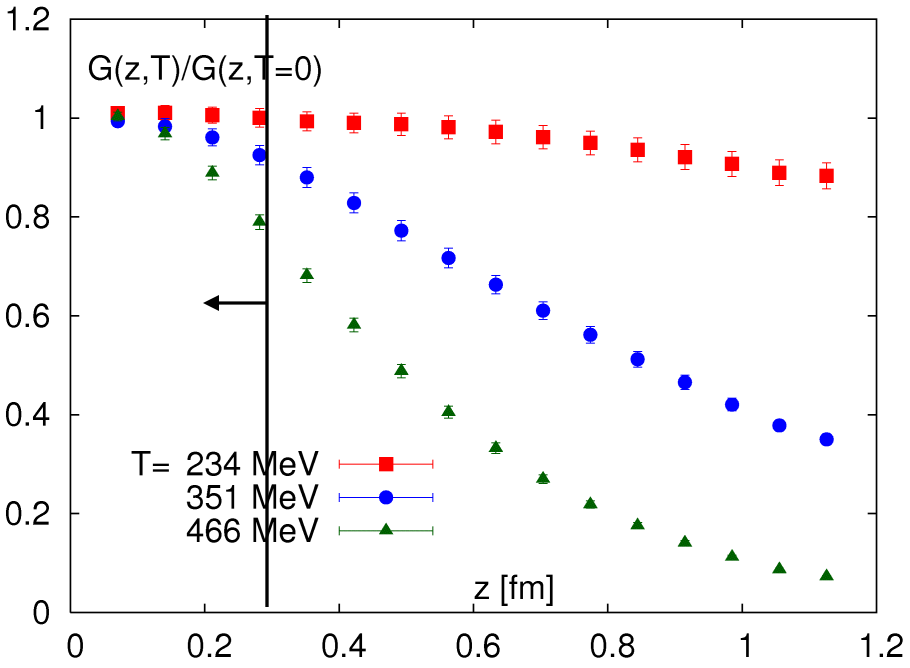
High T limit :

$m_{scr}(T) \simeq 2\sqrt{m_c^2 + (\pi T)^2}$

p4 action, dynamical *(2+1)-f* 32^3x*8* and 32^3x*12* lattices

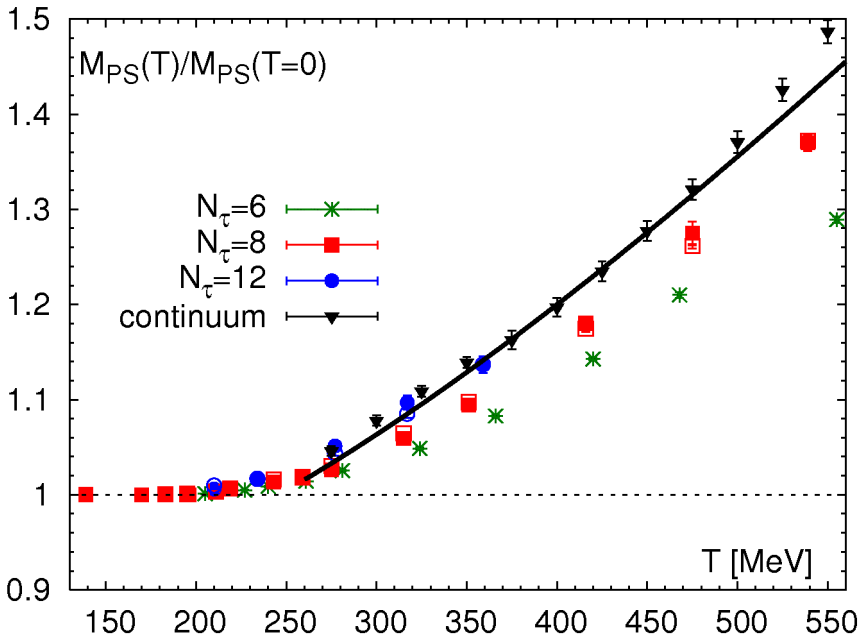
Significant temperature dependence already for *T=234* MeV, large *T*-dependence in the deconfined phase

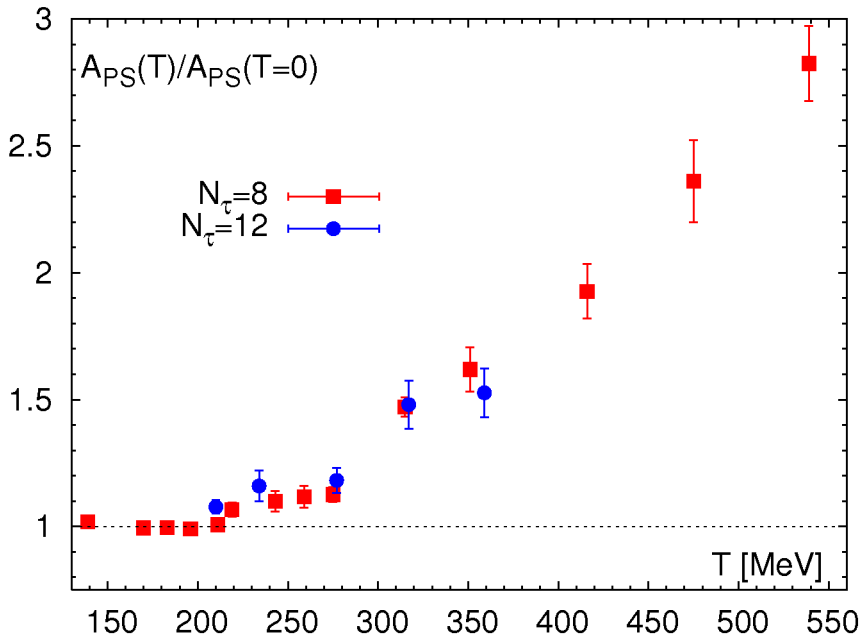
For small separations *(z T<1/2)* significant *T*-dependence is seen



Spatial charmonium correlators at large distances

pseudo-scalar channel => 1S state , point sources: filled; wall sources: open

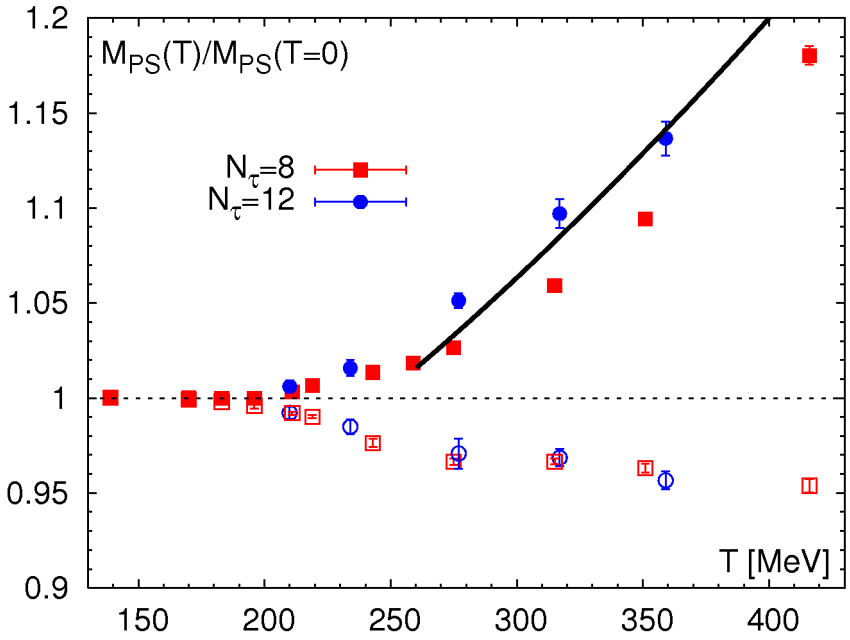


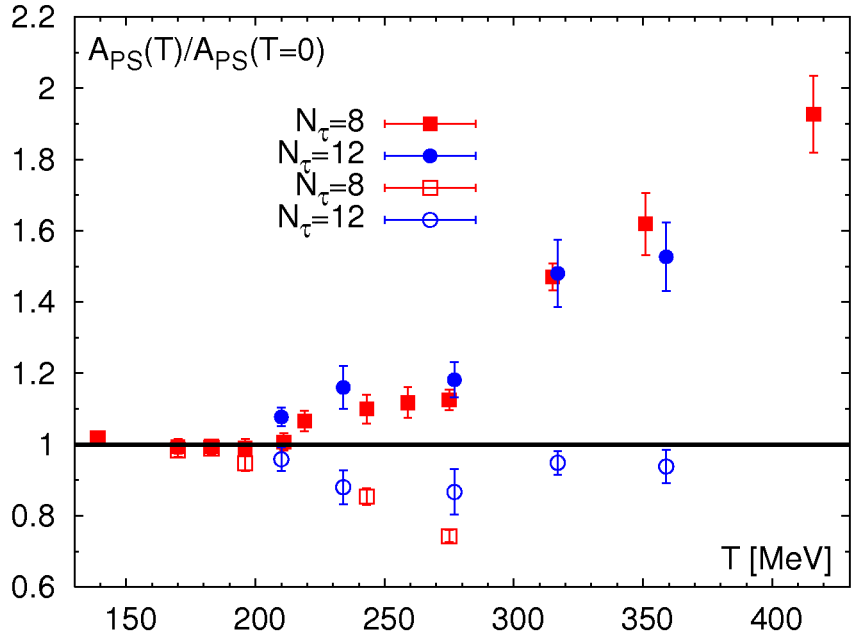


- no *T*-dependence in the screening masses and amplitudes (wave functions) for ***T<200*** **MeV**
- moderate *T*-dependence for ***200<T<275*** **MeV** => medium modification of the ground state
- Strong *T*-dependence of the screening masses and amplitudes for ***T>300*** **MeV**, compatible with free quark behavior assuming m_c***=1.28*** **GeV** => dissolution of 1S charmonium !

Dependence of the correlators on boundary conditions

For compact bound states there is no dependence on the temporal boundary conditions in the correlators (quark and anti-quark cannot pick up the thermal momentun)





- no dependence on the boundary conditions for ***T<200* MeV**
- moderate dependence on the boundary conditions for ***200* MeV<*T*<*275* MeV**
- strong dependence of the screening masses and amplitudes for ***T>300* MeV**
  => dissolution of 1S charmonium !

Myth #1 :
Lattice QCD tells that quarkonium states survive up to *2Tc*

Busted !

Based on :

1) Analysis of the charmonium correlators and systematic uncertainties in the lattice spectral functions,

2) lattice QCD based potential model

3) analysis of the spatial charmonium correlators

Myth #2 :
It is unclear whether the internal energy or the free energy or their combination should be used in the potential models

Strong vs. weak binding scenario in the two component model interpretation of the J/ψ R_{AA} data depends on the choice of the potential
Zhao, Rapp, PRC 82 (2010) 064905

Why potential model ?

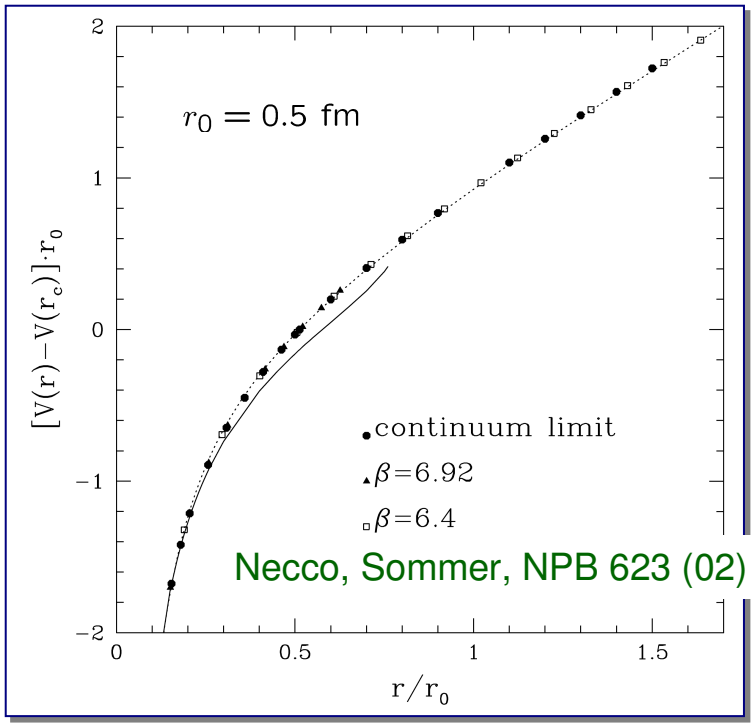
What is calculated in lattice QCD $T>0$?

How to define the potential at $T>0$?

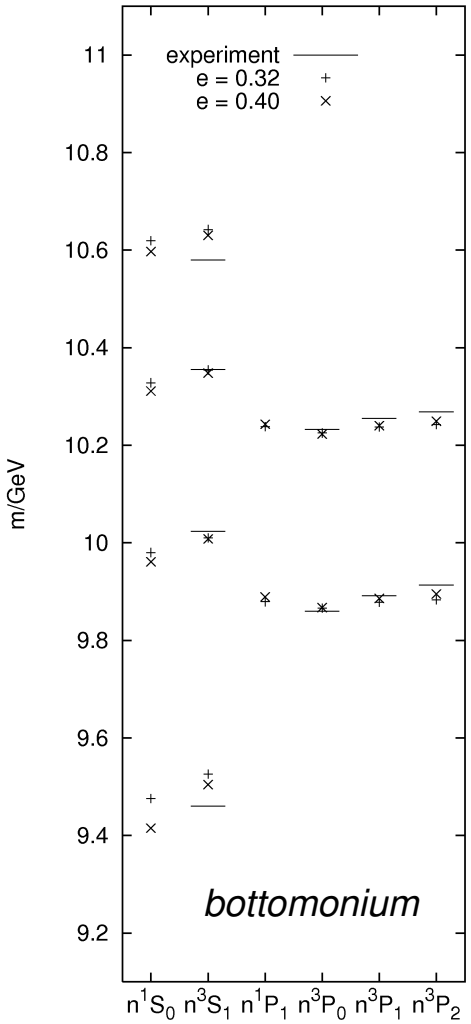
So what ?

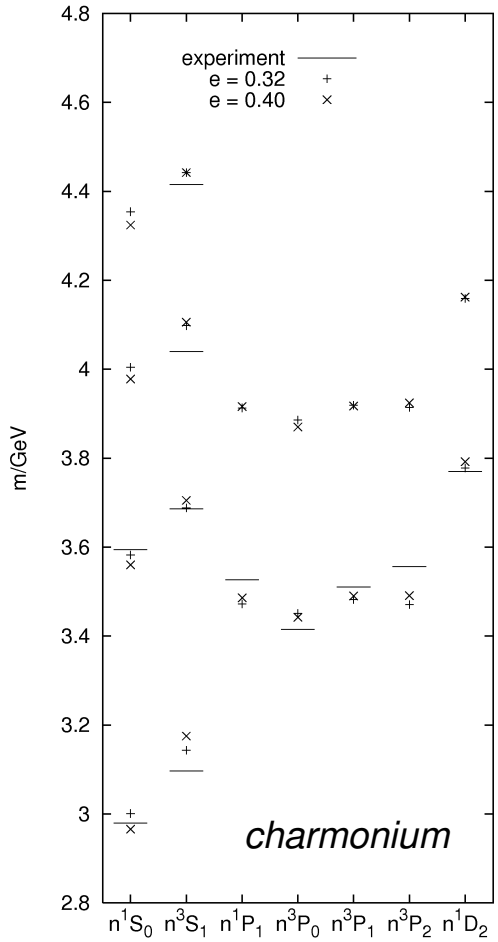
Potential model at T=0

Lattice QCD ⇒ Schrödinger equation ⇒ Quarkonium spectra



Necco, Sommer, NPB 623 (02) 271





Bali, Schilling, Wachter PRD56 (1997) 2566

What is calcul Correlation functions of static quarks

McLerran, Svetitsky, PRD 24 (81) 450

$\psi_a^\dagger(\tau,x)$, $\psi_a(\tau,x)$-creation annihilation operators for static quarks at time τ and position x

$\psi_a^{\dagger c}(\tau,x)$, $\psi_a^c(\tau,x)$-creation annihilation operators for static anti-quarks at time τ and position x

$$[\psi_a(\tau,x),\psi_b^\dagger(\tau,y)]_+ = \delta(x-y)\delta_{ab}$$

$$(-i\partial_\tau - gA_0(\tau,x))\,\psi(\tau,x) = 0 \Rightarrow$$

$$\psi(\tau,x) = \mathcal{P}\exp\left(ig\int_0^\tau d\tau' A_0(\tau',x)\right)\psi(0,x) = W(x)\psi(0,x)$$

Consider general correlation function:

$$\mathcal{G}_{aa'bb'}(x,y;\beta,0) = \sum_{s'} < s'|e^{-\beta H}\psi_a(\beta,x)\psi_b^c(\beta,y)\psi_{a'}^\dagger(0,x)\psi_{b'}^{\dagger c}(0,y)|s' >$$

$$N_c = 3,\ 3\otimes\bar{3} = 1\oplus 8: \qquad P_1 = \frac{1}{9}I\otimes I - \frac{2}{3}t^\alpha\bar{t}^\alpha, P_8 = \frac{8}{9}I\otimes I + \frac{2}{3}t^\alpha\bar{t}^\alpha$$

$$G_1(r,T) = \mathrm{Tr}(P_1\mathcal{G})/(\mathrm{Tr}P_1) = \frac{1}{3}\mathrm{Tr}\langle W(x)W^\dagger(y)\rangle$$

$$G_8(r,T) = \mathrm{Tr}(P_8\mathcal{G})/(\mathrm{Tr}P_8) = \frac{1}{8}\langle \mathrm{Tr}W(x)\mathrm{Tr}W^\dagger(y)\rangle - \frac{1}{8}\cdot\frac{1}{3}\mathrm{Tr}\langle W(x)W^\dagger(y)\rangle$$

Correlation functions of static quarks

$$Z_{Q\bar{Q}}(r,T) = \frac{1}{9}\mathrm{Tr}\mathcal{G} = \frac{1}{9}\langle \mathrm{Tr}W(x)\mathrm{Tr}W^{\dagger}(y)\rangle = \exp(-F_{Q\bar{Q}}(r,T))$$

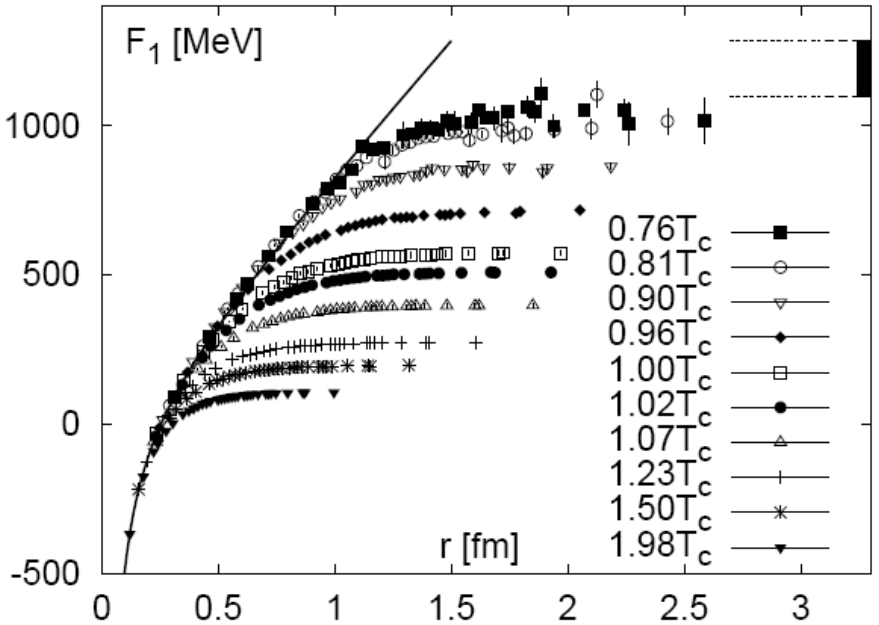
$$Z_{Q\bar{Q}}(r,T) = \frac{1}{9}G_1(r,T) + \frac{8}{9}G_8(r,T) \equiv \frac{1}{9}e^{-F_1(r,T)/T} + \frac{8}{9}e^{-F_8(r,T)/T}$$

The singlet and octet correlators are usually defined in Coulomb gauge but at short distances (*r<1/T*) they are gauge independent

Brambilla, Ghiglieri, P.P., Vairo, PRD 82 (2010) 074019

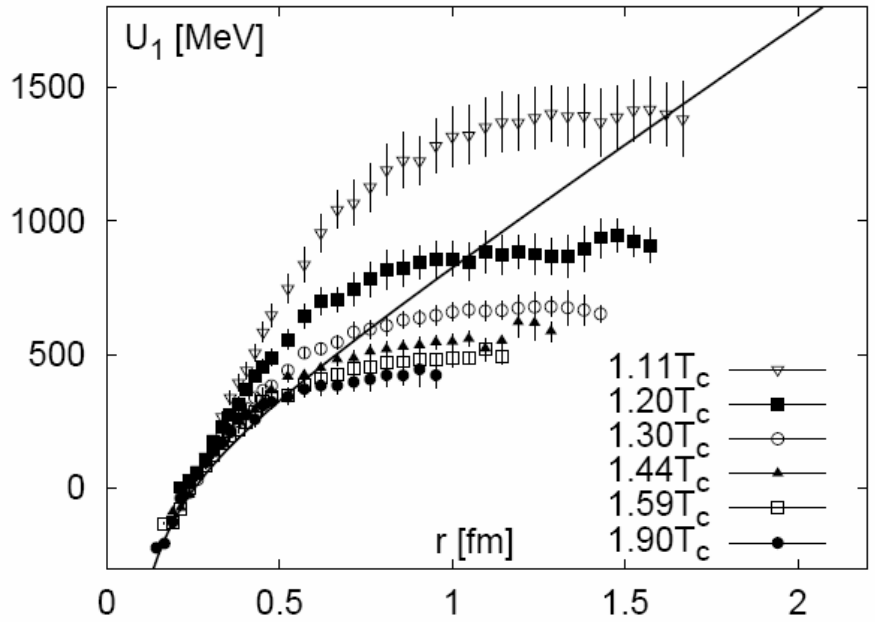
singlet free energy

Zantow, Kaczmarek Eur.Phys.J. C43 (2005) 63



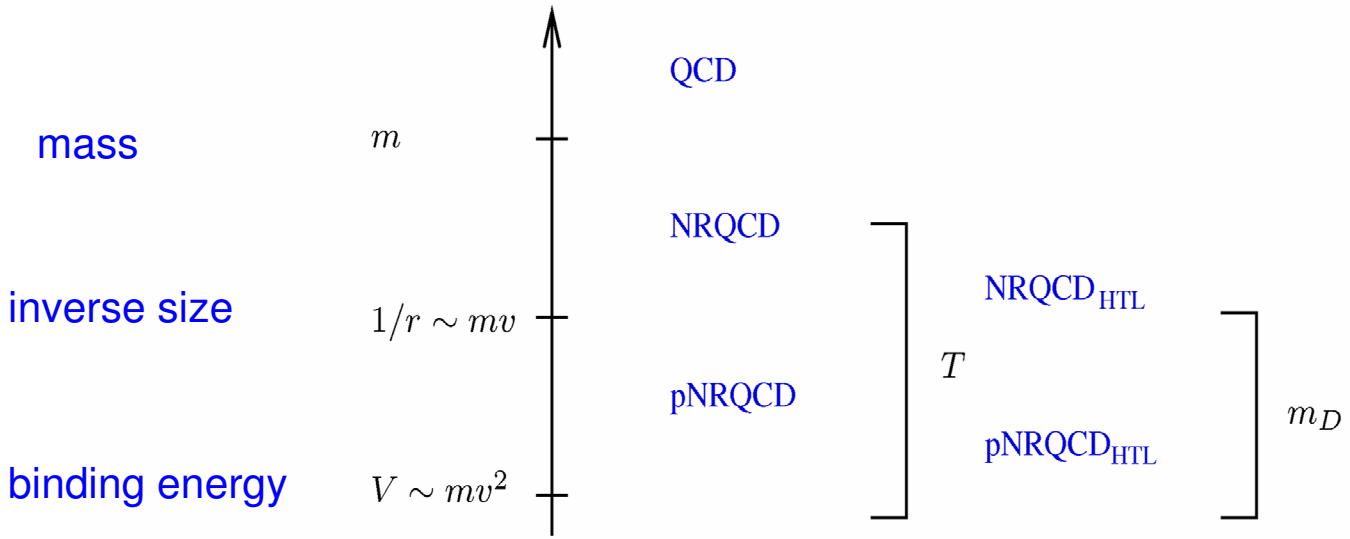
singlet internal energy

$$U_1(r,T) = -T^2\frac{\partial(F_1(r,T)/T)}{\partial T}$$



Effective field theory approach for heavy quark bound states

The heavy quark mass provides a hierarchy of different energy scales



The scale separation allows to construct sequence of effective field theories: NRQCD, pNRQCD

Potential model appears as the tree level approximation of the EFT and can be systematically improved

Brambilla, Ghiglieri, P.P., Vairo, PRD 78 (08) 014017

pNRQCD at finite temperature for static quarks

EFT for energy scale : $E_{bind} \sim \Delta V = (V_o - V_s) \sim mv^2$

Ultrasoft quark and gluons

$$\mathcal{L} = -\frac{1}{4} F^a_{\mu\nu} F^{a\,\mu\nu} + \sum_{i=1}^{n_f} \bar{q}_i \, i \not{D} q_i$$

Singlet $Q\bar{Q}$ field Octet $Q\bar{Q}$ field

$$+ \int d^3r \; \mathrm{Tr} \left\{ \mathrm{S}^\dagger \left[i\partial_0 - \frac{-\nabla^2}{m} - V_s(r,T) \right] \mathrm{S} + \mathrm{O}^\dagger \left[iD_0 - \frac{-\nabla^2}{m} - V_o(r,T) \right] \mathrm{O} \right\}$$

$$+ V_A \, \mathrm{Tr} \left\{ \mathrm{O}^\dagger \vec{r} \cdot g\vec{E} \, \mathrm{S} + \mathrm{S}^\dagger \vec{r} \cdot g\vec{E} \, \mathrm{O} \right\} + \frac{V_B}{2} \mathrm{Tr} \left\{ \mathrm{O}^\dagger \vec{r} \cdot g\vec{E} \, \mathrm{O} + \mathrm{O}^\dagger \mathrm{O} \vec{r} \cdot g\vec{E} \right\} + \ldots$$

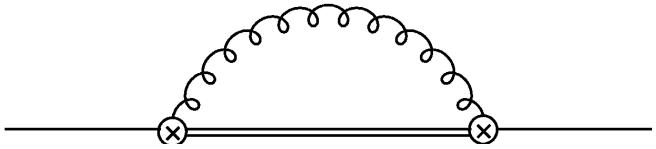
potential is the matching parameter of EFT !

Free field limit => Schrödinger equation

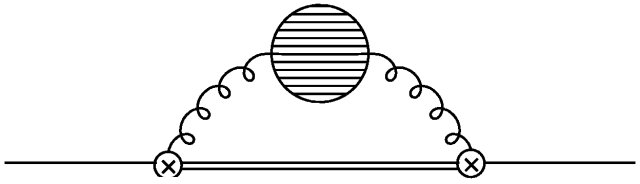
$$\left[i\partial_0 - \frac{-\nabla^2}{m} - V_s(r,T) \right] S(r,t) = 0$$

$E_{bind} \sim \Delta V \sim \alpha_s / r \ll T, \; m_D$ there are thermal contribution to the potentials

Singlet-octet transition :



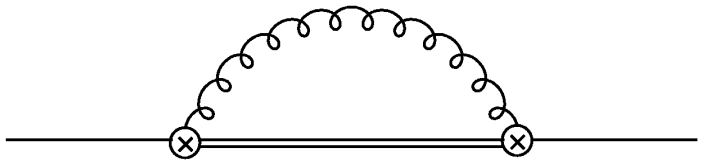
Landau damping :



Brambilla, Ghiglieri, P.P., Vairo, PRD 78 (08) 014017

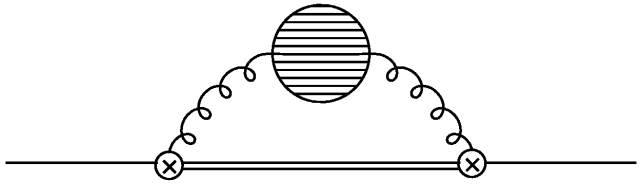
The potential for $r \ll 1/T \ll 1/m_D$

	$\mathrm{Re}V_s(r,T)$	$\mathrm{Im}V_s(r,T)$
$1/r$:	$-C_F\dfrac{\alpha_s}{r}$	0



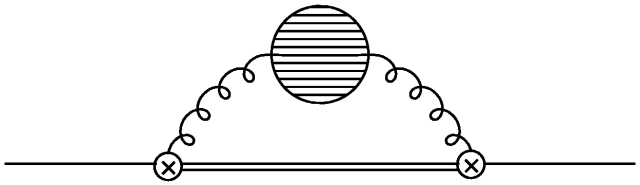
$\Delta V = V_o - V_s$

T:	$g^2T^3r^2 \times \dfrac{\Delta V}{T} \sim \alpha_s^2 T^2 r$	$g^2T^3r^2 \times \left(\dfrac{\Delta V}{T}\right)^2 \sim \alpha_s^3 T$



T:	$g^2T^3r^2 \times \left(\dfrac{m_D}{T}\right)^2$	$g^2T^3r^2 \times \left(\dfrac{m_D}{T}\right)^2$
m_D:	$g^2T^3r^2 \times \left(\dfrac{m_D}{T}\right)^3$	$g^2T^3r^2 \times \left(\dfrac{m_D}{T}\right)^2$

The potential for $r \ll 1/m_D$:



	$\mathrm{Re}V_s(r,T)$	$\mathrm{Im}V_s(r,T)$
$1/r$:	$-C_F\frac{\alpha_s}{r} - C_F\alpha_s T^2 r\left(\frac{m_D}{T}\right)^2$	$g^2T^3r^2 \times \left(\frac{m_D}{T}\right)^2$
m_D:	$g^2T^3r^2 \times \left(\frac{m_D}{T}\right)^3$	$g^2T^3r^2 \times \left(\frac{m_D}{T}\right)^2$

The potential for $r \sim 1/m_D$:

$$V_s(r,T) = -C_F\frac{\alpha_s}{r}\exp(-m_D r) - C_F\alpha_s m_D - iC_F\alpha_s T\left(1 - \frac{2}{rm_D}\int_0^\infty dx \frac{\sin(rm_D x)}{(x^2+1)^2}\right)$$

Laine, Philipsen, Romatschke, Tassler, JHEP 073 (2007) 054

$\mathrm{Re}V_s(r,T)$ is identical to the LO singlet free energy $F_1(r,T)$

The potential is neither the singlet free energy nor the singlet internal energy; it has real and imaginary part. Only in the special case of $r \sim 1/m_D$ the real part of the potential is the same as the singlet free energy

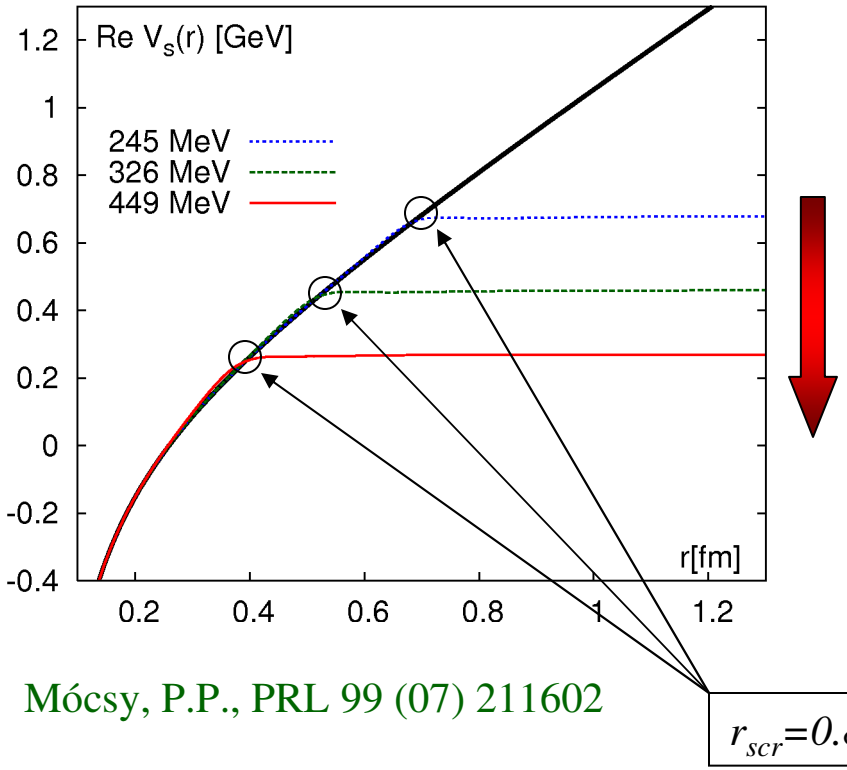
pNRQCD beyond weak coupling and potential models

Above deconfinement the binding energy is reduced and eventually $E_{bind} \sim m\mathrm{v}^2$ is the smallest scale in the problem (zero binding) $2\pi T,\ m_D,\ \Lambda_{QCD} >> m\mathrm{v}^2$ => most of medium effects can be described by a T-dependent potential

Determine the potential by non-perturbative matching to static quark anti-quark potential calculated on the lattice

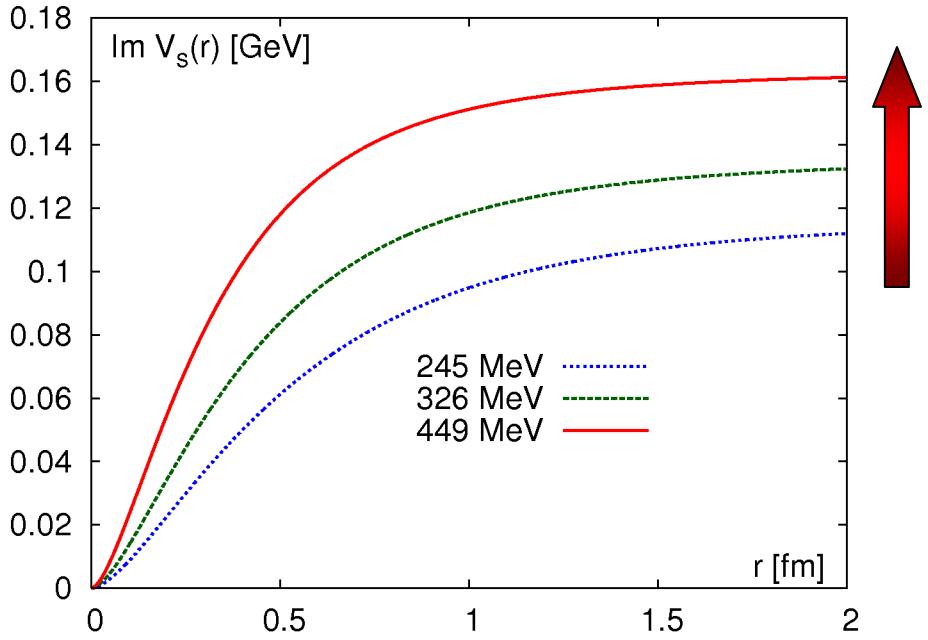
Caveat : it is difficult to extract static quark anti-quark energies from lattice correlators => constrain Re$V_s(r)$ by lattice QCD data on the singlet free energy, take Im$V_s(r)$ from pQCD calculations

"Maximal" value for the real part



Mócsy, P.P., PRL 99 (07) 211602

Minimal (perturbative) value for imaginary part



Laine et al, JHEP0703 (07) 054,
Beraudo, arXiv:0812.1130

The role of the imaginary part for charmonium

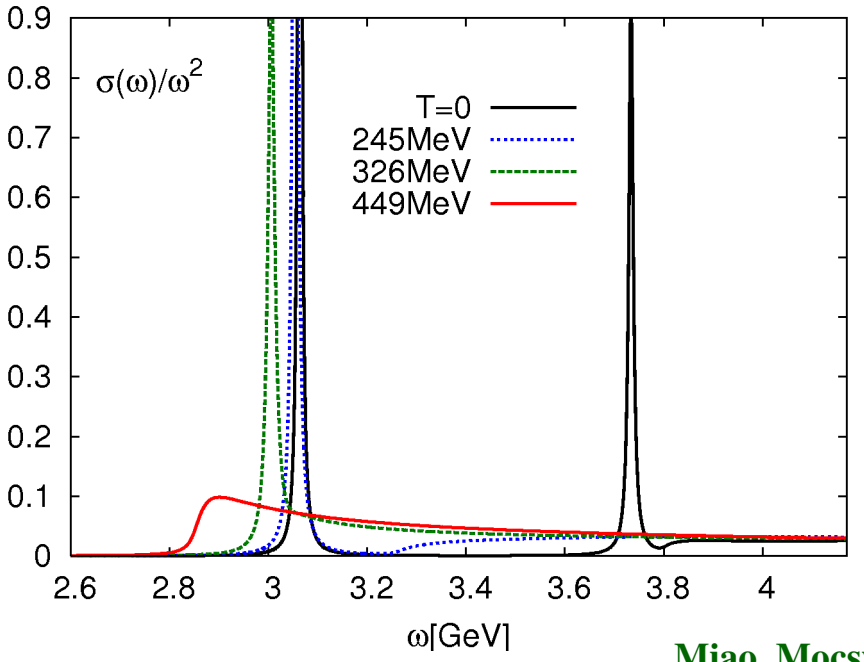
Take the upper limit for the real part of the potential allowed by lattice calculations

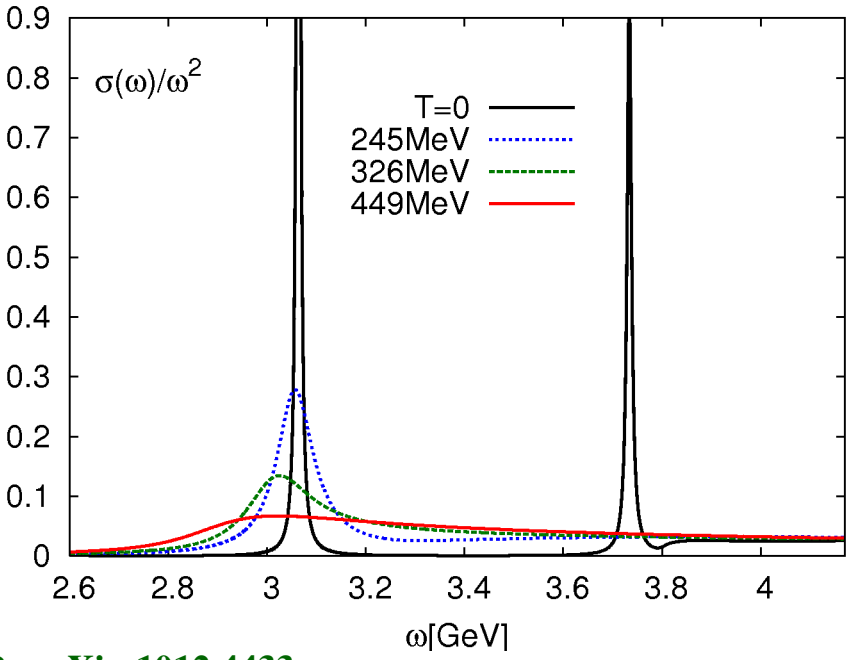
Mócsy, P.P., PRL 99 (07) 211602,

Take the perturbative imaginary part
Burnier, Laine, Vepsalainen JHEP 0801 (08) 043

Im $V_s(r)$ *=0 :*
1S state survives for T = *330* MeV

imaginary part of $V_s(r)$ is included :
all states dissolves for T>*240* MeV





Miao, Mocsy, P.P., arXiv:1012.4433

no charmonium state could survive for T> *240* MeV
this is consistent with our earlier analysis of **Mócsy, P.P., PRL 99 (07) 211602** (T_{dec} ~ *204MeV*)
as well as with **Riek and Rapp, arXiv:1012.0019 [nucl-th]**

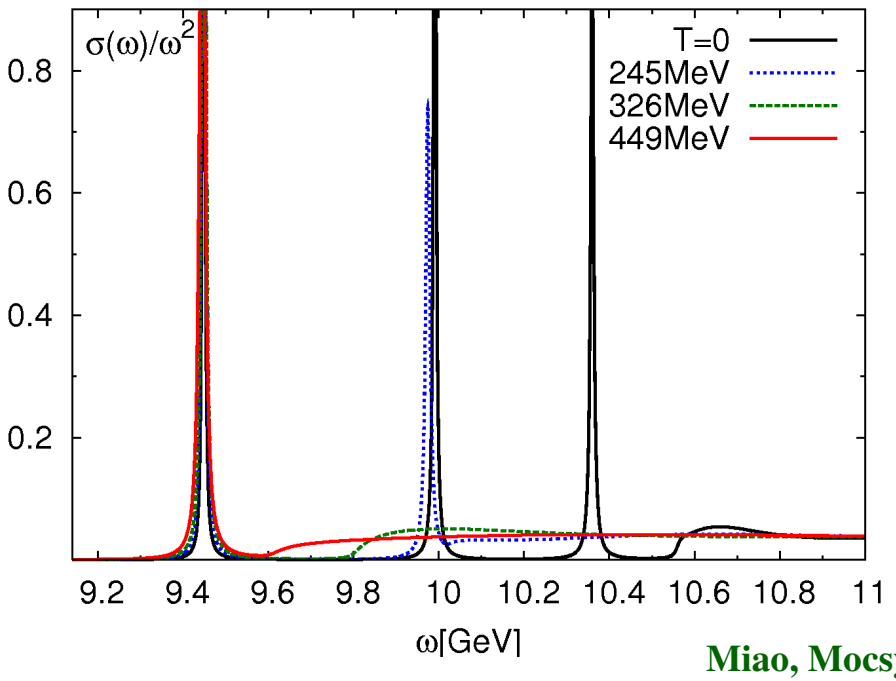
The role of the imaginary part for bottomonium

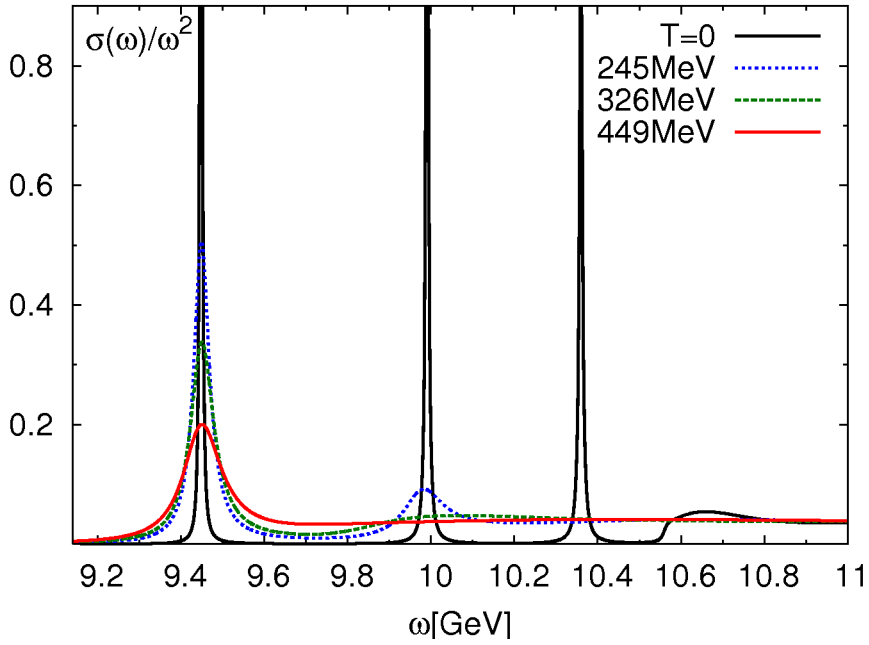
Take the upper limit for the real part of the potential allowed by lattice calculations
Mócsy, P.P., PRL 99 (07) 211602,

Im $V_s(r)$ *=0:*
2S state survives for $T > 245$ MeV
1S state could survive for $T>450$ MeV

Take the perturbative imaginary part
Burnier, Laine, Vepsalainen JHEP 0801 (08) 043

with imaginary part:
2S state dissolves for $T>245$ MeV
1S states dissolves for $T>450$ MeV





Miao, Mocsy, P.P., arXiv:1012.4433

Excited bottomonium states melt for $T \approx 250$ MeV ; 1S state melts for $T \approx 450$ MeV
this is consistent with our earlier analysis of **Mócsy, P.P., PRL 99 (07) 211602** ($T_{dec} \sim 204MeV$)
as well as with **Riek and Rapp, arXiv:1012.0019 [nucl-th]**

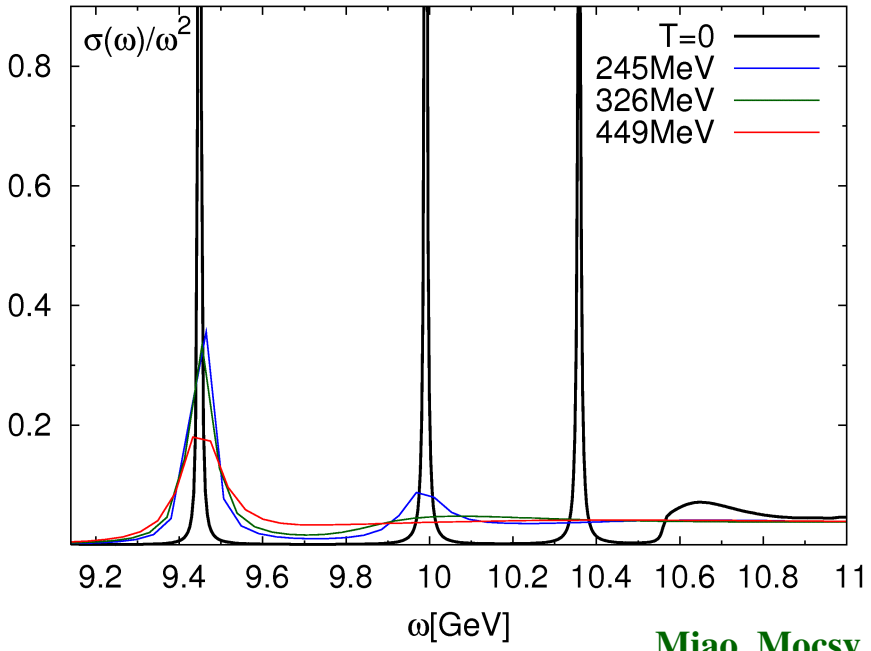
Sensitivity of the spectral functions to real part ofthe potential

Constraints : $F_1(r,T) < \mathrm{Re}V_s(r,T) < U_1(r,T)$

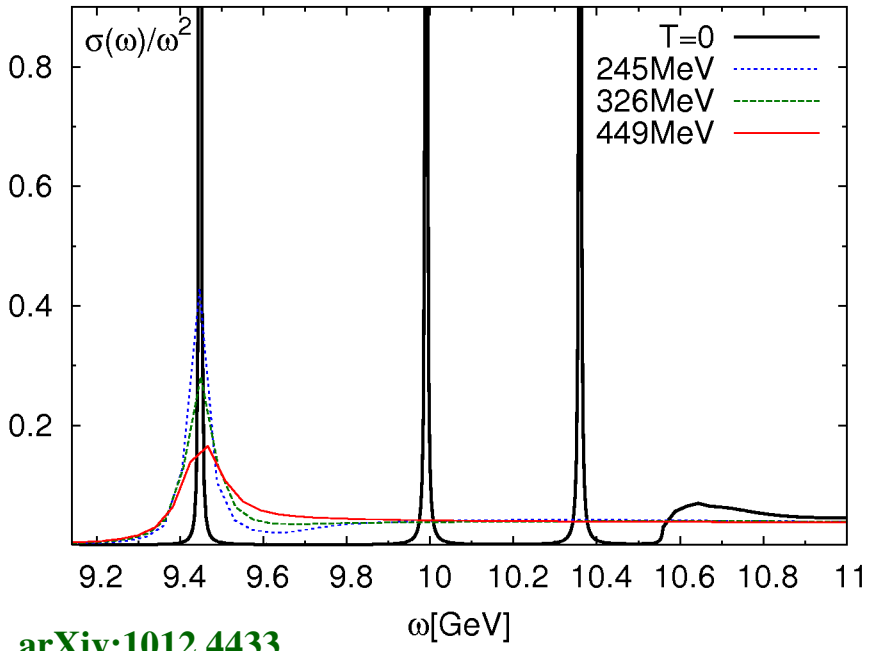
• If the potential is chosen to be close to the free energy charmonium states dissolve for $T \approx 250$ MeV even if the imaginary part is neglected

• For 1S bottomonium melting does not happen for any choice of the real part

Maximally binding real part



Minimally binding real part



Miao, Mocsy, P.P., arXiv:1012.4433

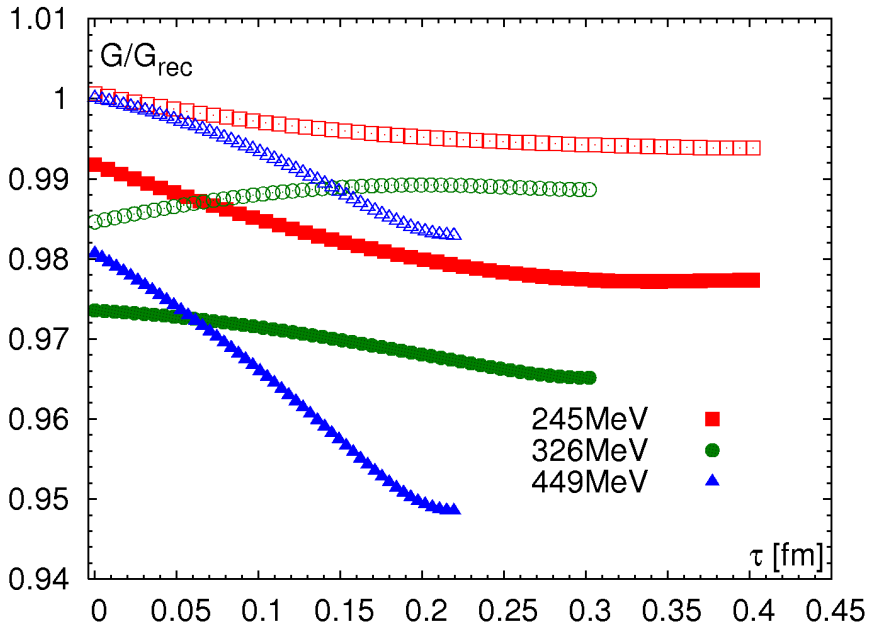
⇨ the shape of the bottomonium spectral functions is not very sensitive to the choice of the real part

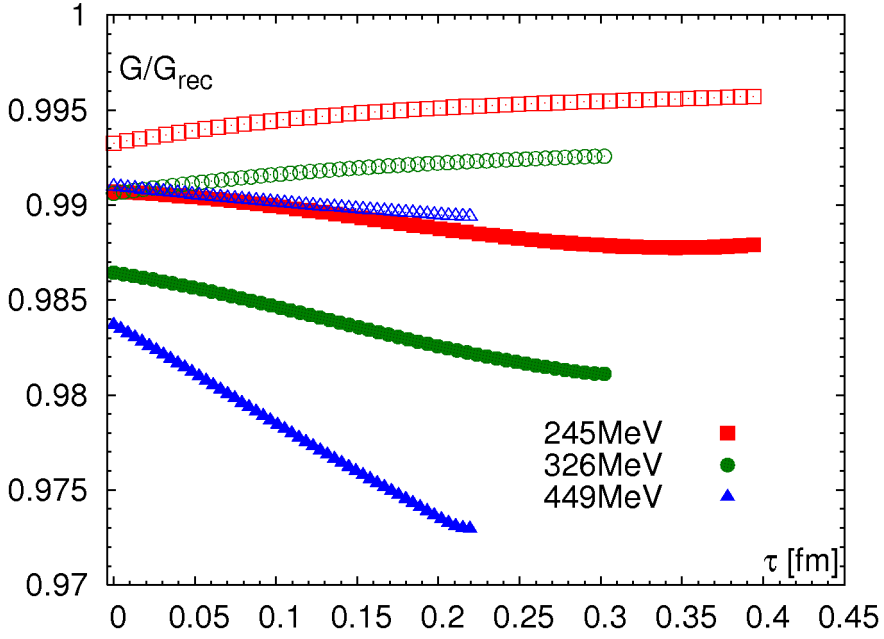
From spectral functions to Euclidean correlators

Charmonium

Bottomonium

open symbols : imaginary part =0 ; filled symbols imaginary part is included





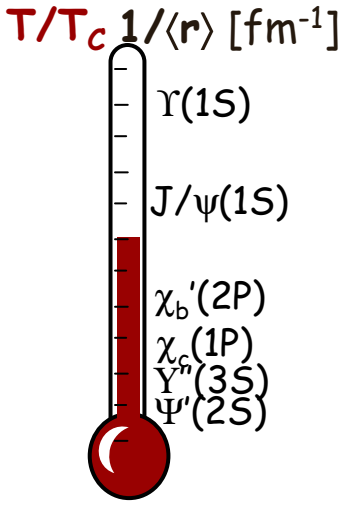
small temperature dependence of the Euclidean correlators, inclusion of the imaginary part and the consequent dissolutions of quarkonium states only lead to (1-4)% reduction of the correlators

Myth #2 :
It is unclear whether the internal energy or the free energy or their combination should be used in the potential models

Busted !

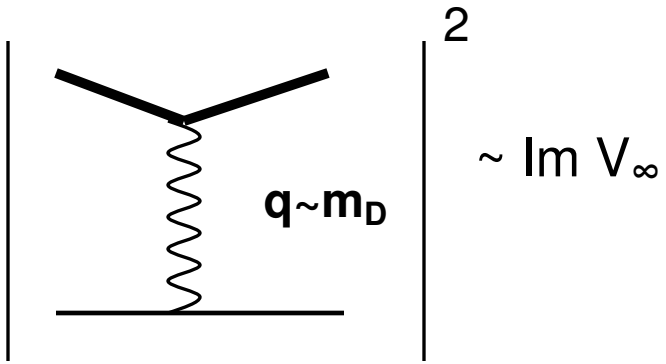
The potential is neither the singlet free energy nor the singlet internal energy and it is complex; the biggest uncertainty in the potential models comes from the imaginary part and assuming a perturbative value for it leads to dissolution of quarkonium states for $T<250MeV$ except for $\Upsilon(1S)$.

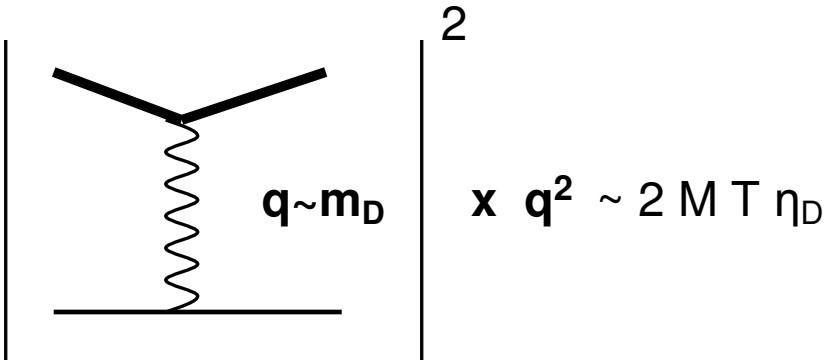
Myth #3
Quarkonium yield measures Debye screening in the hot medium and thus its temperature



Quarkonium spectral function in equilibrium are determined by the real and imaginary part of the potential :
Real part => Debye screening
Imaginary part => heavy quark drag/diffusion

$$\text{Im } V_\infty \sim 2\, M\, T\, \eta_D / m_D^2$$





Dynamical model for charmonium suppression at RHIC

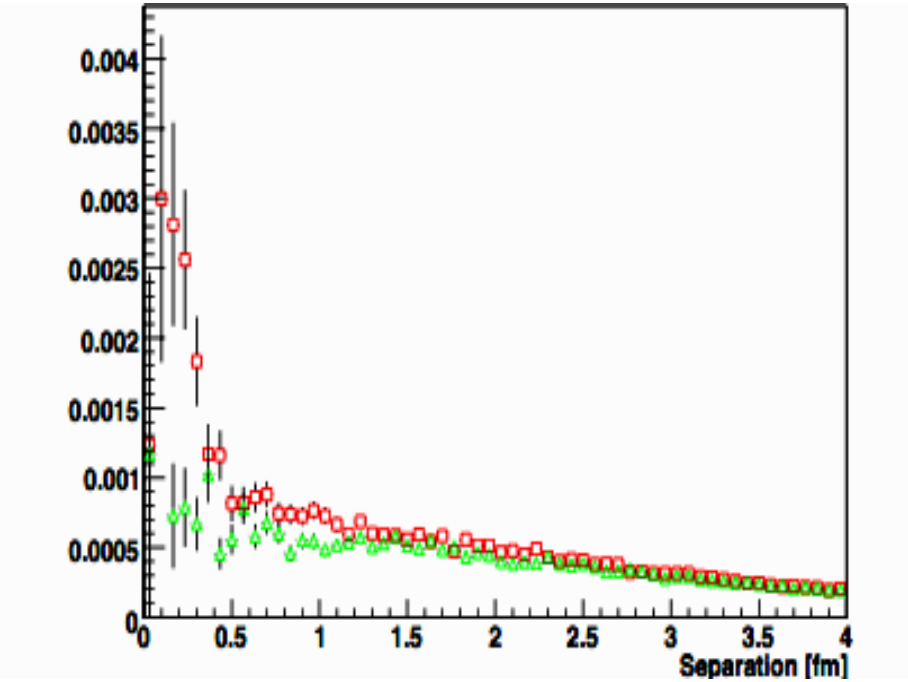
Charmonium is formed inside the deconfined medium (QGP formation < *1fm* @ RHIC)
The charmonium yield at RHIC is determined not only by the in-medium interaction of charm quark and anti-quark but also by the in-medium charm diffusion (drag)

Svetitsky PRD37 (88) 2484

$$\frac{dp_i}{dt} = -\eta_D p_i + \xi_i(t) - \nabla_i V$$

attractive force between quark and anti-quark

$$\frac{dr_i}{dt} = \frac{p_i}{m}$$



1) diffusion constant from analysis of open charm yield
Moore, Teaney, PRC71 (05) 064904

2) the bulk matter is simulated by *(2+1)d* hydro (*ε=p/3*)

3) *V* is taken from lattice QCD

4) initial charm distribution from PYTHIA

The lifetime of QGP at RHIC is not long enough to completely de-correlate the initially correlated quark anti-quark pairs

Young, Shuryak, arXiv:0803.2866 [nucl-th]

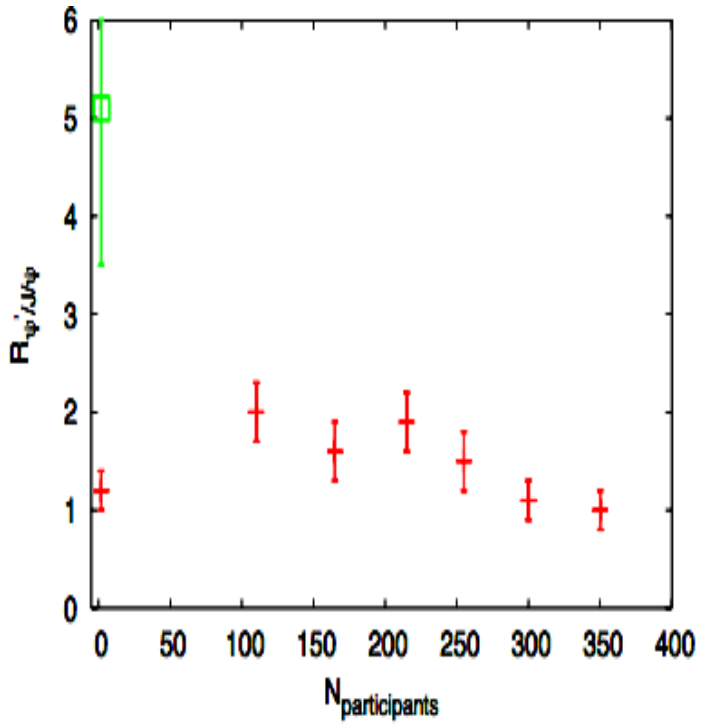
Ratio of ψ' to J/ψ (mock thermal equilibrium):

Out-off equilibrium distribution $f(E)$ very similar in shape to thermal ones $f_0(E)$

$$R_{\psi'/J/\psi} = \left(\frac{f(E_{bin}^{J/\psi})}{f_0(E_{bin}^{J/\psi})}\right) / \left(\frac{f(E_{bin}^{\psi'})}{f_0(E_{bin}^{\psi'})}\right)$$

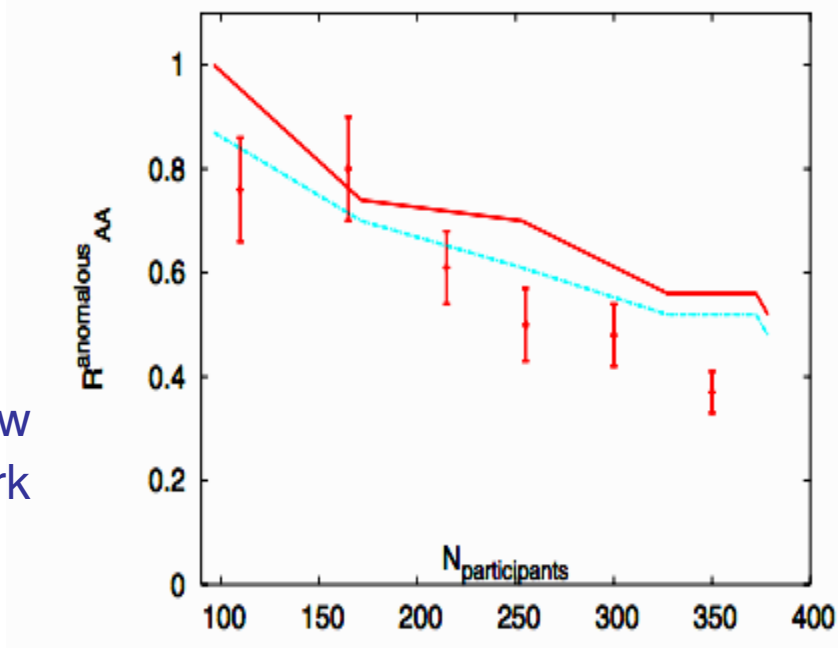
$R_{\psi'/J/\psi} \approx 1$ as observed by NA50

but it is due to quasi-equlibrium and not true thermal equlibrium



Feed-down from excited states :

$$N_{J/\psi}^{final} = N_{J/\psi}^{direct}\left[1 + R_{\psi'/\psi}\sum_i \left(\frac{g_i}{3}\right)\exp\left(-\frac{\Delta M_i}{T}\right)B_i\right]$$



Open questions :

What are p_T, y distributions and anisotropic flow of J/ψ and recombination of un-correlated quark anti-quark pairs from the Langevin dynamics ?

Myth #3
Quarkonium yield measures Debye screening in the hot medium and thus its temperature

Partially true !

Quarkonium yields are sensitive to both the Debye screening and the heavy quark diffusion. Even when we see sequential suppression of quarkonium states at the level of spectral function it probably will not be observable in quarkonium yields, excited quarkonium states may be still produced at the freezout at the rate determined by the corresponding Boltzmann factors.

There is yet another myth around :

Quarkonium production in elementary collisions (pp, e^+e^-, ep) is not understood at all, pNRQCD/color octet model completely fail (e.g. J.P. Lansberg)

recent progress : global pNRQCD fit, fragmentation approach,
see :

BNL Summer Program on Quarkonium production in elementary and heavy ion collisions
http://www.bnl.gov/qpworkshop/

QWG 2011 Workshop
http://qwg2011.gsi.de/